APPLICATION OF A RESISTANCE MOISTURE METER TO HVI STRENGTH MEASUREMENTS

R. K. Byler, W. S. Anthony

ABSTRACT. *A series of four studies were conducted with the assistance of two U.S. Department of Agriculture Agricultural Marketing Service offices to determine the range of fiber moisture encountered in cotton classing and to examine the potential of using on-line moisture readings to assist with fiber strength readings. These studies showed that the meter could be used with the existing high volume instrument (HVI) cotton classing equipment and that the measured moisture content (m.c.) correlated with the HVI strength, as it should. The first study, conducted at the Memphis Quality Control Section, demonstrated the usefulness of the resistance moisture meter and showed a strong relationship between measured m.c. and HVI strength. The second study was conducted at the Greenwood, Mississippi, Classing Office (CO) during the regular classing season to determine if the meter could operate under CO production conditions and determine the range of moisture contents which must be measured. The meter functioned well during the classing season. The measured m.c. of cotton samples was found to have a greater range than expected during classing and was directly proportional to the HVI strength. Ninety-four percent of the samples were within the range of 6.3% to 7.6% wet basis (w.b.) but the entire observed range was 5.8% to 10.0% w.b. The third study was conducted at the Greenwood CO on samples prepared at the U.S. Cotton Ginning Laboratory, USDA, ARS, Stoneville, Mississippi, and ginned under several moisture treatments. Ginning machines and post-ginning moisture treatment affected the fiber m.c. relatively little, but a significant reduction in strength was attributed to ginning at m.c. below 7% w.b. The fourth study was conducted at the Greenwood CO where samples were subjected to nonstandard moisture conditions and then HVI classed. This study showed that even when the m.c. variation measured by the experimental meter was low (0.3% w.b.) there was a measurable effect on HVI strength. All four studies resulted in a significant correlation between the measured m.c. and the measured HVI strength showing that the resistance moisture meter is a promising addition to the HVI classing line.*

Keywords. *Cotton, Moisture content, Measurement, Resistance, Strength.*

The tensile strength of fibers has long been considered to be an important cotton property and is included in the High Volume Instrument (HVI) measurements made by the Agricultural Marketing Service (AMS) of the U.S. Department of Agriculture as part of the classification of cotton. The moisture content (m.c.) of fiber and of the testing atmosphere is known to affect the strength of individual cotton fibers (Moore and Griffin, 1964) and the fiber strength measurements (Lawson et al., 1976), among others. Wilde (1990) showed that corrections based on a relative humidity measurement could substantially reduce uncontrolled variation of HVI strength due to atmospheric changes. The U.S. Cotton Ginning Laboratory (USCGL) has developed (Byler, 1998) and patented (Byler and Anthony, 1996) a new resistance moisture meter which is fast, accurate, and reasonably inexpensive. Presumably a measurement of the m.c. of cotton fibers made during fiber strength testing could be used to reduce the variability in strength measurement results due to the moisture content variation (Byler et al., 1993). Resistance moisture measurements could be added to the HVI strength measurement system if the moisture meter were fast and accurate enough. The moisture content data could potentially be used to mathematically correct the strength readings to a standard moisture content or to simply indicate to the operator that a sample was not within an acceptable moisture range.

PURPOSE

The purpose of this study was to examine relationships between fiber moisture as measured by the newly developed moisture meter and HVI strength and to gain experience in using the meter under commercial conditions.

MATERIALS AND METHODS

This study was carried out in four parts, the first was conducted at the Quality Control Section, AMS Cotton Division, Memphis, Tennessee, facility; the second, third, and fourth parts were carried out at the Greenwood Classing Office (CO), AMS Cotton Division, Greenwood, Mississippi.

PART 1 — PROTOTYPE TESTING

A prototype of a newly designed resistance-type moisture meter was built into the platen of a Motion

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Control Model 3000 HVI color/trash meter so that a moisture measurement could be taken during the HVI test sequence. The reference method for measuring lint moisture content was the oven method (Shepherd, 1972) which has an expected standard deviation of 0.25%, w.b. The prototype was calibrated with a standard error of 0.3% w.b. with samples which had a "normal" amount of trash, 2% total waste as determined by the Shirley Analyzer test (ASTM, 1978). For this part of the study, the moisture meter was installed adjacent to a Motion Control Model 3500 HVI system in the Quality Control Section at Memphis, Tennessee. The AMS had prepared lint samples by taking 15 samples from each of six bales of cotton of different known strengths. Five samples from each bale were stored for a week under normal relative humidity and temperature for a CO [21.1°C (70°F) and 65% relative humidity (RH)], five samples of each bale were stored under drier than normal conditions and five samples were stored under more humid than normal conditions. The HVI was operated with standard operating procedures by AMS personnel. Four strength readings were taken for each sample and averaged for the HVI strength measurement for that sample. After each sample had been measured with the HVI system, four measurements of the moisture content were made on the prototype machine by AMS personnel. After part one, the prototype was returned to the USCGL where the calibration was checked. The additional calibration data did not result in a statistically significantly different calibration equation.

PART 2 — COMMERCIAL CONDITIONS, SAMPLES FROM ONE REGION

The prototype was then installed near a Zellweger Uster Model 900 HVI system at the Greenwood CO and operated between 23 November and 14 December 1992, while samples were being classed for cotton producers. During that time, four moisture measurements were taken on different portions of each sample. The moisture data was identified by the same bar coded gin identification (ID) and the bale number as was used for classing. Climatic conditions in the sample storage and testing rooms were maintained at 21.1 ± 0.6°C (70 ± 1°F) and 65 ± 2% RH. The moisture content of selected samples was checked by AMS personnel with a hand-held resistance-type moisture meter to assure that the samples were in the range 6.75% to 8.25% dry basis (6.3% to 7.6% w.b.). The purpose of this study was to gather data on the range of moisture contents experienced in a CO and to determine if there were any important design problems in incorporating the moisture meter into an HVI line.

PART 3 — EFFECT OF M.C. TREATMENT DURING GINNING ON HVI STRENGTH

The purpose of this study was to examine the relationship between ginning procedures, the m.c. measured by the resistance method, and the HVI strength. The main question was whether drying and moisture restoration after ginning would affect the moisture content while classing and thereby the HVI strength measurements. Samples were prepared for HVI strength and resistance moisture measurement at the CO. The controlled variables were:

1. Cotton variety.
2. Cotton cleaning (both seed cotton and lint cleaning).
3. Moisture content at the gin stand.
4. Post-ginning moisture treatment.

There were two varieties in the study, DES 119 and DPL 51. There were two gin cleaning levels, "standard" (with three seed cotton cleaners and two lint cleaners) and "minimal" (using only the extractor-feeder and the gin stand as cleaners). The four moisture levels at ginning resulted from storing samples at two different relative humidity levels higher than ambient conditions, storing samples under ambient conditions, and drying samples previously stored at ambient conditions. Two moisture treatments after ginning (putting the samples directly into standard CO conditions and putting them into a high moisture environment for several days before sending them to be classed) were used. The samples were treated normally after they were sent to the CO, which meant that they were exposed to standard CO conditions for several days before data were collected.

PART 4 — COMMERCIAL TESTING, SAMPLES FROM SEVERAL REGIONS

The purpose of this study was to use the newly developed resistance moisture meter in conjunction with an HVI line on several hundred cotton samples to determine if the moisture measurement showed promise in correcting HVI strength readings for moisture and thereby reduce the variation in HVI strength readings at the CO with samples from several cotton producing regions of the U.S.

For this study, samples were obtained by AMS from five CO regions and sent to the Greenwood CO where they were treated in two nonstandard environments (the air lock and the office environment were used). One hundred different samples each day were brought into the standard environment from the nonstandard environments but the samples were kept in a plastic bag until testing began for a sample. They were HVI classed and tested for moisture content immediately, and then twice more during the same day. They were exposed to standard conditions after the first set of measurements and approached equilibrium with the standard conditions during the day. Each sample had a bar code bale tag which included the gin ID. The first two digits of the gin ID were a prefix which identified the CO of origin effectually identifying the area of growth of each sample. Testing began in early March 1993, and the procedure was repeated for seven days. The first day was used as a procedure check and only cotton from the Greenwood CO was used.

RESULTS AND DISCUSSION

PART 1 - PROTOTYPE TESTING

All of the moisture data for cotton with the same pretreatment were averaged and the three moisture levels were found to be 5.6%, 6.6%, and 8.9% w.b. The average standard deviation for the four measurements of moisture for the 90 samples was 0.17%, which is an indication of the repeatability of the moisture measurement. The mean strength and mean moisture measurement for these 18 treatments (6 bales $\times$ 3 moisture levels) are shown in table 1. The strength of the drier cotton was about 2.5 g/tex lower than the cotton at the standard moisture level, and the

Table 1. Moisture and HVI strength measurement means for five samples taken from six different bales of standard cotton fiber conditioned at three humidity levels, Part 1

Treat-ment		Bale 1	2	3	4	5	6
1	Strength*	22.4	21.0	21.2	25.0	28.5	25.0
	Moisture†	5.7	5.5	5.6	5.5	5.6	5.5
2	Strength*	24.8	23.3	23.6	26.8	32.1	27.6
	Moisture†	6.4	6.7	6.7	6.3	6.9	6.2
3	Strength*	32.7	30.2	30.8	35.4	38.1	33.5
	Moisture†	8.9	9.0	9.0	8.9	8.7	8.8
Standard	Strength*	25.6	24.2	25.3	28.0	32.7	27.9

* Strength in g/tex.
† Moisture in percent wet basis.

strength of the wetter cotton was about 6.0 g/tex higher than the strength at the standard moisture level. The average standard deviation of the five repeat strength readings (which were each based on four strength readings) was 0.8 g/tex.

Regression analysis was used to predict the predetermined HVI strength based on the measured strength and measured moisture content for the 90 samples. The R^2 was 0.86 and the root mean square error (RMSE) was 1.1 for the model:

$$SSTR = 20.75 + 0.8544 \times MSTR - 2.47 \times MMC \quad (1)$$

where

SSTR = the standard strength (g/tex)
MSTR = the measured strength (g/tex)
MMC = the measured m.c. (whole percent w.b.)

The model fit the data well and the fact that the RMSE was only somewhat larger than the average standard deviation of the strength readings indicates that a more complex model is probably not justified. Figure 1 shows the original strength data and the data after correction for moisture content using equation 1. The HVI strength readings were observed to vary independently of moisture content, but the variation with moisture content was obvious. Based on figure 1, the new moisture meter appeared to be able to produce data which would be useful in correcting HVI strength readings made on samples which had not been properly exposed to CO conditions.

PART 2 — COMMERCIAL TESTING, SAMPLES FROM ONE REGION

The moisture measurement operator at the Greenwood CO was able to keep up with the HVI line but had some trouble entering the gin code and bale number because of the low quality bar code reader which was available for use at the moisture meter; all samples which did not have a correct gin code and bale number were discarded in this analysis. The mean of the moisture measurements for each bale was calculated. Some bales did not have four separate readings, and the data for all bales with fewer than three readings were discarded. The average standard deviation of the four repeat moisture measurements of different portions of the same sample for the remaining 3940 bales from 68 different gins was 0.07%, which is an indication of the repeatability of the moisture meter. Data for bales with

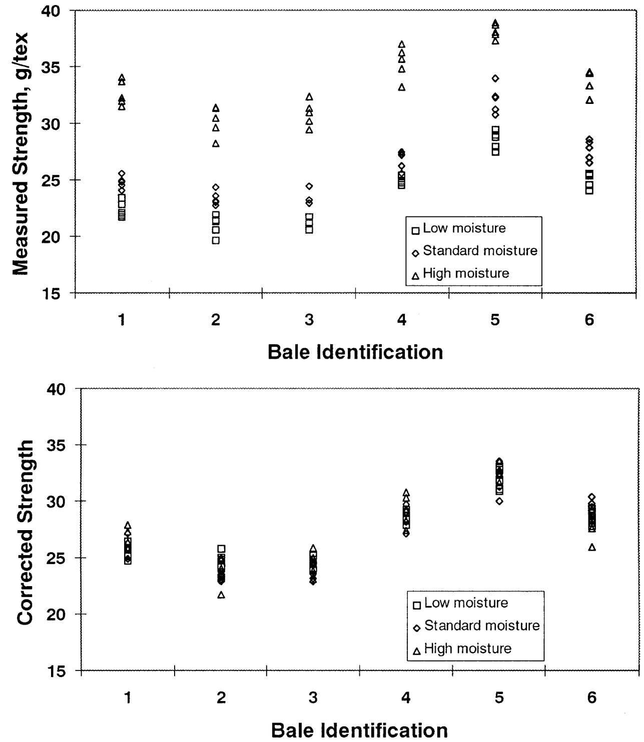

Figure 1–Cotton strength measurements before and after correction for moisture content using equation 1. Note that the strength range for the uncorrected readings was 12 g/tex and 3.6 g/tex for the same readings corrected for measured moisture content.

mean moisture content at the extremes were examined and in no case was there an inconsistency in the individual readings. The standard deviation for the repeat readings of bales with unusually high or low moisture content was not noticeably higher than for the data as a whole. In addition, it was observed in several cases that consecutive bale numbers (but not usually consecutive in classing) had similar extreme readings. The mean of the four different readings of the moisture content was taken as the correct reading for each bale.

The minimum observed moisture content was 5.8%, the maximum was 10.0%, and the mean for the entire study was 6.9%. More than 94% of the observations were within the range 6.3% to 7.6%, which is the range allowed by AMS for HVI testing. Nearly 5% of the observations were above 7.6% and nearly 1% of the observations were below 6.3%.

The HVI and moisture data were combined by gin code and bale number and those samples without both HVI data and moisture data were discarded, with 3,931 bales remaining. The mean strength was 26.5 g/tex and varied from 22.3 to 31.7 g/tex. If moisture content is properly controlled in the CO then there would be no detectable relationship between HVI strength and moisture content unless higher strength cottons have higher equilibrium moisture contents. In part 1 no such relationship was seen (see table 1). Analysis of variance revealed a very high correlation between the measured HVI strength and moisture content ($P < 0.0001$) (table 2).

The variation in observed moisture content was higher than expected, even if a few extreme observations were discarded (without any legitimate reason). The calibration of the moisture meter was checked thoroughly against the

Table 2. Analysis of variance using a linear relationship for predicting the strength with the moisture content measured by the new device for samples chosen while classing, Part 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value
Model	1	455.29	455.29	256
Error	3629	6460.06	1.78	
Corrected total	3630	6915.34		

oven test (Shepherd, 1972) before and after the testing as well as occasionally during the testing. No malfunction or significant shift of the calibration of the meter was observed. Because the Greenwood CO maintained good control of temperature (±0.6°C) and relative humidity (±2% RH), based on checks conducted by the CO personnel, and the moisture readings by the new resistance meter were valid, another explanation of the moisture variation was needed. One could be the effect of hysteresis in equilibrium moisture content (Griffin, 1974). From the hysteresis effect for newly harvested cotton fibers, an approximate range of 1.7% w.b. in moisture content is possible depending on the moisture history of the sample. In this data, 98% of the samples were observed to be within a 1.7% moisture range. Based on the moisture content-strength relationship from part 1, variation in strength caused by a variation in m.c. of 1.7% would be expected to be 4.3 g/tex. About 90% of the strength readings were within the 4.3 g/tex range. Of course, strength variations are also attributed to genetics, growing conditions, and possibly other effects.

Part 3 — Effect of M.C. Treatment During Ginning on HVI Strength

The mean ginning moisture content by variety during this study is shown in table 3. These moisture data were determined by standard oven methods. We hypothesized that by affecting equilibrium moisture content through ginning procedures we could affect the HVI strength. The first part of this study was to see if we could affect the moisture content at the CO.

The analysis of covariance considered variety, ginning moisture content, moisture treatment after ginning, amount of cleaning machinery, and all first-order interactions in a model of the observed moisture content at the CO. The analysis showed that the post-ginning moisture treatment, variety, and the drying with post-ginning moisture treatment interaction all had a statistically significant effect (probability of larger F by chance < 0.01) on the moisture content at the CO. However, the effects were small, for example the variety DES 119 had a moisture content 0.06 higher than DPL 51. This difference was statistically significant (with 84 observations) but the expected effect on HVI strength would be about 0.1 g/tex. Similarly, the samples which had been held at higher humidity than CO conditions for several days had a moisture content 0.06 higher than those which had not. The only conditions which produced moisture content differences which were of real interest were for the lowest moisture content at ginning. Samples with post-ginning storage at higher humidity resulted in moistures 0.17% w.b. higher than those directly transferred to CO conditions. The moisture content at classing for the other combinations of ginning moisture content and post-ginning treatment were not significantly different.

Thus, this study indicated that the moisture content at classing can be affected only slightly by ginning techniques such as drying and moisture restoration. These results are not consistent with research by Griffin (1974) on newly harvested cotton which implied a greater influence of ginning techniques on the moisture content at classing, in the range of 1.7%. More recently Barker (1992) showed the hysteresis of the cotton fiber he studied to be about 1%. One possible explanation of the lower moisture hysteresis of the fiber in this study was that the cotton used in this study was not newly harvested. It had been dried to storage moisture content in the field and stored as seed cotton in trailers for four months before testing. The cotton was stored in a high humidity environment before ginning to obtain the high moisture content in this study. The reduction of the hysteresis between drying and rewetting of agricultural products after repeated cycles has been documented by several researchers, for example Chung and Pfost (1967) and Henderson (1970) discuss their own studies and work by others. The hysteresis in moisture content may have been reduced in this study due to the moisture cycling which would have occurred to these samples before they were studied.

Analysis of HVI strength by analysis of covariance considered ginning m.c., variety, cleaning equipment, moisture content at classing, moisture treatment after ginning, and all first-order interactions in a model to explain the observed strength data. The analysis showed that only the ginning moisture content had a significant effect on the HVI strength. Although the high humidity post-ginning treatment resulted in higher strength for every combination of variety and ginning moisture content, the average difference was only 0.15 g/tex which was not significant. Also, DES 119 had higher strength than DPL 51 for every ginning moisture content, but the average difference was only 0.17 g/tex which was not statistically significant. Combining the data for which the effects were not significant produced table 4. The differences in moisture content found in the first part of this analysis did not result in a statistically significant variation in HVI strength because of the small variations of moisture within the other,

Table 3. Mean moisture content at ginning by treatment and variety, Part 3

	Variety	
Moisture Content	DES 119	DPL 51
Low	2.7	2.4
Medium	5.5	5.4
High	7.1	7.1
Very high	8.3	8.3

Table 4. Means of the data showing the statistically significant factors, ginning moisture content, and HVI strength determined by standard methods, Part 3

Moisture at Ginning (%)	Moisture at Classing (%)	Strength (g/tex)
2.5 d	6.32 b	25.7 c
5.4 c	6.35 a,b	26.4 b
7.1 b	6.35 a,b	27.2 a
8.3 a	6.40 a	27.1 a

Note: Means followed by different letters were significantly different.

statistically significant categories and because of the relatively large uncontrolled variation in the strength data.

The strength means at the lower three moisture contents were significantly different from each other but the strengths from cotton ginned at 7.1% and 8.3% were not significantly different. Thus, we can conclude that this study showed that the ginning moisture content affects the HVI strength, low moisture ginning produces lower strength and high moisture produces higher strength. There was no significant difference in HVI strength between samples from ginning with no lint cleaning and ginning followed by two saw-type lint cleaners. Because there was so little difference in the moisture content at classing, 0.2% to 0.3% across categories, the reason for this relationship was not a difference of moisture content during classing. Something appeared to be happening during fiber-seed separation, however, to reduce fiber strength at lower moisture content The fact that the moisture treatments did not result in significant differences in HVI strength supports the current approach to controlling the effects of moisture at the CO. However, the patterns found suggest that if the HVI strength readings were more accurate then the moisture effects may become detectable in the strength readings. Also, the effect of humidity conditions on moisture content may be more pronounced for freshly harvested samples. Most of the samples at the CO would be considered to be freshly harvested.

Analyses of the HVI trash and moisture content data showed that there was no significant correlation between the HVI trash reading and the resistance moisture measurement for HVI trash levels that ranged from 0.1 to 3.0% of the sample surface area (the calculated slope was about 0.001% m.c. w.b. per 1% change of HVI trash which is not statistically different from zero). The oven test was not performed to verify this conclusion. As mentioned earlier, the meter was calibrated with normally ginned lint which contained some trash. Another method of measuring cotton moisture, using near infrared light, changed about 0.2% m.c. dry basis over this trash range (Taylor, 1990).

PART 4 — COMMERCIAL TESTING, SAMPLES FROM SEVERAL REGIONS

The change of moisture content and the time interval averages were tabulated (table 5) between the first and last measurement for each sample. The conditions were such that the samples stored in the air lock were drier in every case and gained moisture during storage under standard conditions. The change of m.c. from the nonstandard storage conditions to the standard conditions was small, the average was 0.28% w.b.

Table 5. Average time interval from the first measurement to the last measurement for each sample on a test day and the observed moisture change, Part 4

Test Day	Time Interval (h)	Moisture Change (%)	Final Moisture (%)	Standard Deviation
2	3.8	0.26	7.0	---
3	3.8	0.13	6.8	0.15
4	4.5	0.28	6.4	0.17
5	4.1	0.28	6.4	0.16
6	3.9	0.44	6.4	0.15
7	1.6	0.30	6.4	0.13
Average	3.6	0.28	6.6	0.28

Table 6. Final moisture content means (% w.b.) by CO and day of test, Part 4

	Day of Test				
Classing Office	2	3	4	5	6
Rayville	6.92	6.82	6.48	6.48	---
Greenwood	7.08	6.81	6.40	6.38	6.37
Abilene	6.84	6.73	6.40	6.37	6.31
Phoenix	---	7.09	6.52	6.36	6.48
Visalia	6.92	6.76	6.47	6.49	6.39
			LSD = 0.08		

The change of moisture content and the final moisture content data were examined for correlation with CO of origin of the sample and the conclusion was drawn that the moisture content was not correlated with the CO of origin. This means that the measured moisture content did not change with the growth conditions and varieties represented by these samples. There were differences in the measured moisture content (table 6) but they were for the most part not statistically different, and for those which were statistically different the differences were so small they were considered to not be meaningful for strength correction (less than ±0.2% w.b.) considering the accuracy of the HVI strength instrument.

SUMMARY AND CONCLUSIONS

In Part 1, HVI strength was directly proportional to the lint moisture content at about 2.5 g/tex per percent moisture content in the range 5.6% to 8.9% w.b. The combination of measuring HVI strength and m.c. allowed the strength readings of samples which were not at the correct moisture content to be corrected so that they were similar to data obtained at the correct moisture content.

In Part 2, significant variation was observed in the lint moisture content of samples conditioned under common climatic conditions. A significant correlation was found between the observed moisture content and the HVI strength. The moisture meter operated satisfactorily for reading 3,940 samples four times each except for the bar code reader which was of an older design and difficult to use. The minimum observed moisture content was 5.8% w.b. and the maximum was 10.0% for a range wider than expected.

In Part 3, the ginning process affected lint moisture content at ginning and this moisture content change was detectable at the CO after holding the samples in the conditioning room for three or more days; however, the effect was smaller than anticipated. The explanation for the difference in the equilibrium curves obtained by Griffin and the apparent equilibrium relationship in this study is that Griffin's data was for newly harvested cotton and these samples were not newly harvested and had experienced an unknown number of drying-rewetting cycles. The explanation of the moisture content in the gin process affecting equilibrium which affected the strength was not supported by this data (from an experiment designed to study such a relationship).

In Part 4, we concluded that the resistance moisture meter can operate in the CO and measure moisture content with considerable repeatability (about ±0.1% w.b.). The final moisture content was not correlated with CO of origin of the sample, which implies that different varieties of cotton grown under different climates will register the same moisture content with this meter when exposed to identical environmental conditions. The samples did not experience much change in moisture content in this study (average of 0.28% w.b.) resulting in a small change in strength; therefore, it was not necessary to make a "correction" in the strength readings.

In summary of all four parts, the new resistance moisture meter provided a means to quickly assess the moisture content of lint cotton and this measurement of moisture content was correlated with changes in measured HVI strength. The moisture content readings could be used to correct strength readings made at non-standard moisture content levels to be similar to those made with standard procedures. An accurate strength correction equation which covers the full range of potential moisture content is needed.

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